Investigations of Surface Topography of Hot Working Tool Steel Manufactured with the Use of 3D Print

Pawel Grobelny [1,*], *Lukasz* Furmanski[1] and *Stanislaw* Legutko[1]

[1]Faculty of Mechanical Engineering and Management, Poznan University of Technology, 3 Piotrowo St., 60-965 Poznan, Poland

Abstract. The paper presents the possibilities of 3D printing of chosen hot working tool steel for manufacturing ready made parts. Results of examination of the surface topography of material manufactured by the technology Laser CUSING®B (Laser melting with metals) on the machine, Concept Laser M1 3D printing of metal parts has the potential to revolutionize the market of manufacturing and supplying parts. It makes it possible to dissipate manufacturing and to produce parts on request at lower cost and less energy consumption. The parameters of the surface topography of the hot working tool steel directly after printing can differ depending on the distance from the base plate. The differences of surface roughness values can amount from 32% to 85% for *Ra* and from 59% to 85% for *Rz* in comparison of the sample bottom to its top.

1 Introduction

3D print is one of the most perspective technologies of manufacturing. Nowadays, 3D print develops very quickly and becomes more and more competitive to the traditional methods of prototyping, modelling and production. It finds application in many aspects of our life, from medicine and biomechanics through such branches as automotive, aircraft industry, film production to art, jewellery, furniture production and fashion [1]. Application of hot working tool steel:

- inserts with conformal cooling for injection moulds [2], [3],
- inserts with conformal cooling for pressure casting dies of zinc, magnesium and aluminium alloys,
- bodies of cutting tools with designed cooling channels,
- building of highly complicated parts for which strength and hardness are essential,
- prototyping small steel elements with elevated mechanical strength, and resistant utility parts.

2 Material used in the tests

The application of the Laser CUSING technology makes it possible to create element of metal with uniform structure, directly from a computer elaborated design [4].

* Corresponding author: pawel.grobelny@gflean.pl

The print is created thanks to the power of high quality laser which precisely sinters the subsequent layers of the selected metal powder. The process takes place in a closed chamber with the participation of nitrogen or argon. The device automatically applies a new powder layer and, depending on the requirements (speed, quality), it is able to make a layer with the thickness of 15 – 500 µm.

Once the process of sintering a layer is completed, the platform, on which the printed object is located, descends, after which the subsequent layer of powder is applied. The Laser CUSING technology makes it possible to produce parts of complex geometry of a material identical to that used in traditional production (e.g. in foundry). General diagram of the Laser CUSING technology functioning (Figure 1). The manufactured elements do not require additional machining of pre-production investments but, in order to improve the technical parameters heat treatment is applied. One of the materials used in incremental manufacturing is hot working tool steel named CL 50 WS whose composition is in accordance with the European Standard 1.2709, German Standard X3NiCoMoTi 18-9-5 and American Standard 18% Ni Maraging 300.

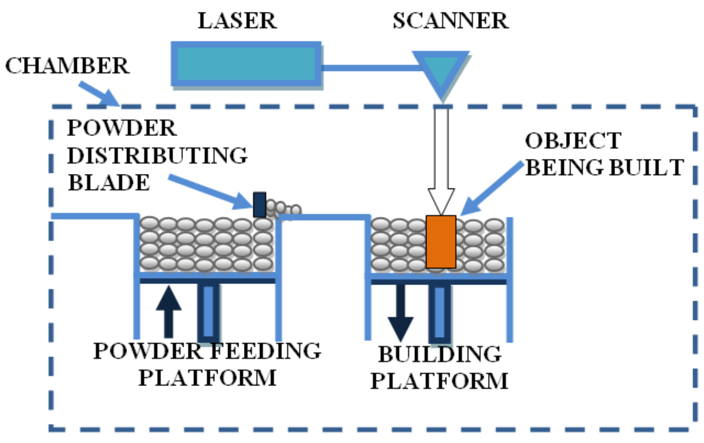


Fig. 1. General diagram of the Laser CUSING technology functioning.

3 Methodology of investigation

In the investigation, hot working tool steel with the chemical composition in accordance with the European standard 1.2709 has been used. Due to its high strength and hardness, the alloy is perfectly suitable for building elements of injection moulds [5], [6]. Thanks to the layer manufacturing by the method of Laser CUSING, it is possible to build forming inserts with cooling channels matching the shape of the part being formed, i.e. with conformal channels. The steel acquires high hardness at the level of up to 52 HRC and competitive strength as compared to the standard material used for building injection and casting moulds [7].

Samples for testing have been printed in vertical position in the shape of shafts diameter of 10 mm and length of 100 mm. They have been designated from A1 to A6 (Figure 2) and have been made on the Concept Laser M1 device.

The authors have made an attempt of characterization of the surface topography of hot working tool steel whose chemical composition is in accordance with the European Standard 1.2709. The topography examination results have been analysed, both for the samples just after 3D printing and after the process of finish machining.

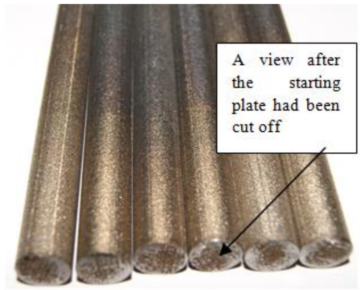


Fig. 2. Samples used in the tests.

The selection of above cutting parameters is recommended for the finish milling of hardened steels [8-10]. The machining tool was equipped with the inserts designated with the following ISO symbol: DCMT 0700204E-UR; T9325 with holder, SDHCL 2525 M11. The printed samples have been subjected to machining under production conditions on the machine MAZAK QTS 250M. The analysis of the machined material surface topography after the process of turning has been performed with the use of HOMMEL-ETAMIC T8000 R device.

4 The results of investigation

The results of the topography measurements have been subjected to statistical processing with the use of the program, digital surf Mountains® surface imaging & metrology software. The diagrams of the alterations of selected roughness parameters of the printed samples, depending on the place of measurement can be seen in Figure 3.

a) b)

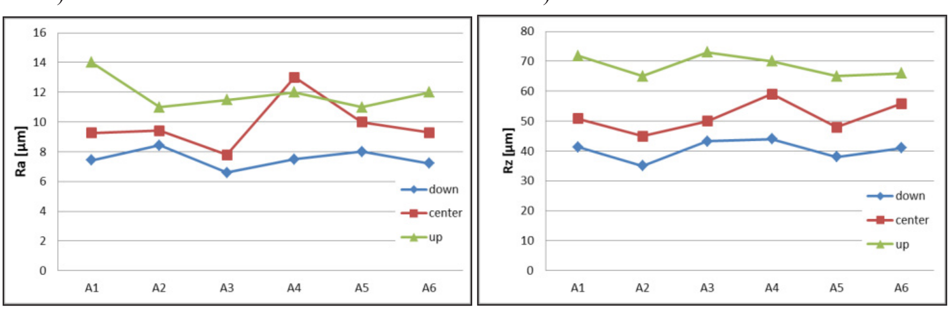
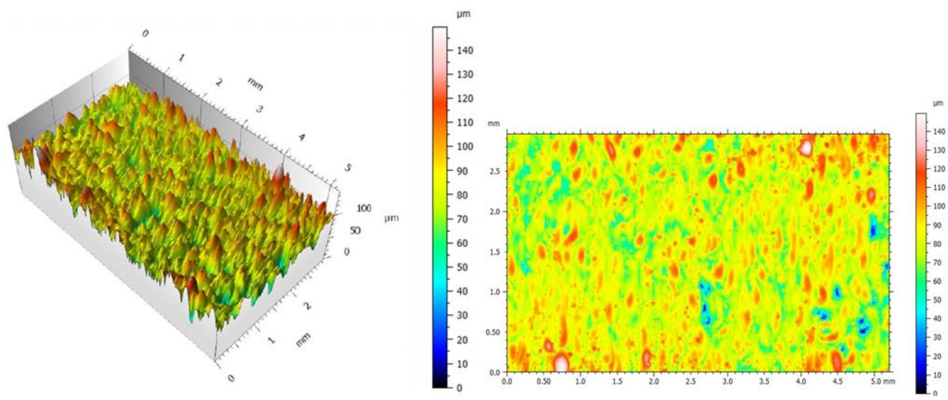


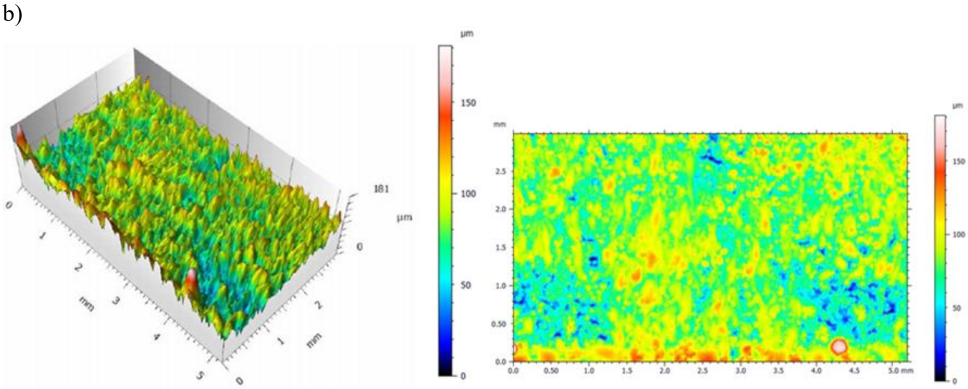
Fig. 3. Alterations of the selected roughness parameters depending on the place of measurement: a) parameter *Ra*, b) parameter *Rz*.

In the analysis of the selected roughness parameters, it has been found that the higher from the base plate, the higher are the values of the parameters under consideration, from 32% to 85% for *Ra* and from 59% to 85% for *Rz* in comparison of the plate bottom to its top. The next step in the analysis of the hot working tool steel, after determination of its roughness parameters, is presentation of the technological surface in the graphic form. Analysis of contour maps and isometric images of constructional surfaces has shown some specific features of those surfaces influencing the functional properties of the surfaces. The appearance of the surface topography has been visually analysed in order to present the characteristics of the out print and the process of turning. Figure 4 shows the out printed surface of sample A1 depending on the place of measurement. It has been found that the surface closer to the base plate is isotropic, i.e. has more evenly distributed peaks (Figure 4a) than the surface in the middle and upper part of the sample. In Figure 4c, one can see a characteristic valley, i.e. long depression of unevenness which can result from the out print kinematics. Higher average roughness values have been observed in the upper part of the sample, which has been reflected in the legend scale.

a)



b)



c)

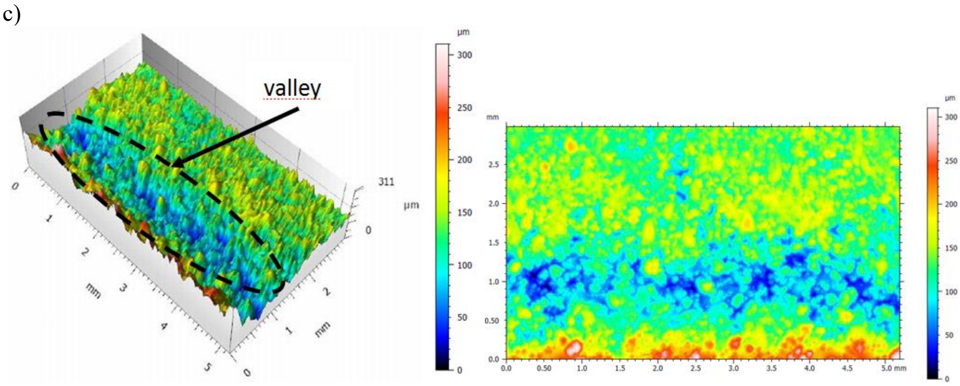


Fig. 4. Surface of sample A1 of 1.2709 after out print depending on the place of measurement, isometric view and contour map: a) bottom, b) middle, c) top.

The parameter of obliqueness *Ssk*, provides information about the surface asymmetry. The value of the *Ssk* parameter indicates prevalence of peaks on the surface for $Ssk > 0$ or prevalence of valleys for $Ssk < 0$ [11]. When the obliqueness values, *Ssk* are negative, most material is located close to the surface peaks. The *Sku* parameter (kurtosis) indicated the occurrence of unexpectedly high peaks or deep valleys for $Sku > 3$ or their absence from the surface for $Sku < 3$. Graphical presentation of the pair of roughness parameters: kurtosis (*Sku*) as compared to obliqueness (*Ssk*) can be seen in Figure 5 [12].

 DOI: 10.1051/matecconf/201713702004

In the process of wear due to, e.g. flow of liquids in inserts with conformal cooling or in tool bodies with cooling channels, the surface obliqueness *Ssk*, is one of the most important parameters due to the effect of roughness shortening [13].

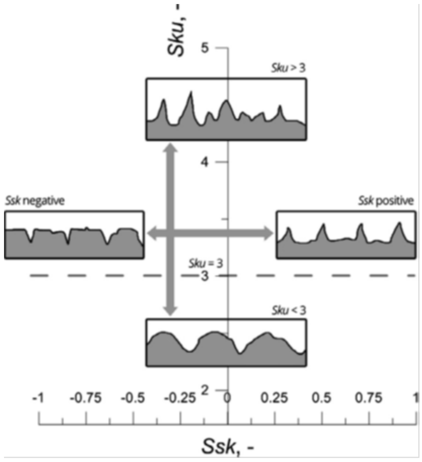


Fig. 5. Graphical representation of surface for *Sku*–*Ssk* maps [12].

Surface wear causes reduction of the *Ssk* value. In Figure 6, one can see the pair of amplitude roughness parameters *Ssk* and *Sku*, of the 1.2709 steel after out print depending on the place of measurement. The particularly high *Sku* for measurement A1 down proves the presence of high peaks on the surface. All the analysed surfaces, regardless of the surface asymmetry, have leptokurtosis shape.

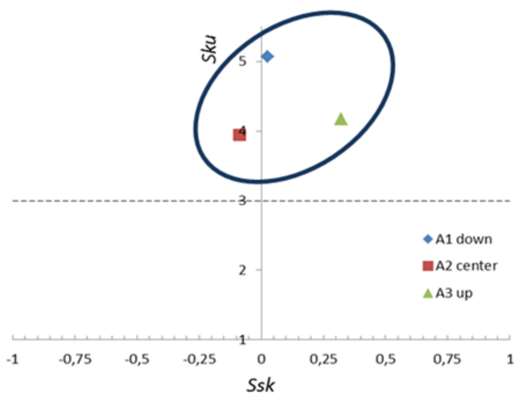


Fig. 6. A pair of amplitude surface roughness parameters, *Ssk* and *Sku*, of the steel, 1.2709, after out print depending on the place of measurement.

After printing the samples have been subjected to machining under production conditions on the machine tool MAZAK QTS 250M. The analysis of the machined material surface topography after the turning process has been performed. For samples A1, A2, A3 areas A (top), B (centre), C (bottom) were cut, which were machined (Fig. 7).

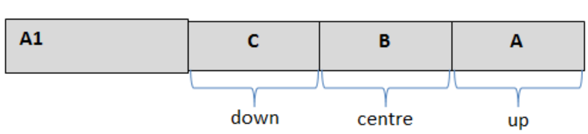


Fig. 7. The areas of sample subjected to turning.

Variable machining parameters for particular areas have been selected: cutting speed v_c = 70 ÷ 100 m/min, feed f = 0.1 ÷ 0.2 mm/ rev, cutting thickness a_p – 0.5 ÷ 0.6 mm. The detailed processing parameters and obtained results of selected surface topography parameters are presented in Table 1.

Table 1. Turning parameters and values of chosen surface topography parameters.

	Sample	A1			A2			A3		
	Area	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
	v_c - m/min	100	100	100	70	70	70	100	100	100
	f - mm/ rev	0,1	0,15	0,2	0,1	0,15	0,2	0,1	0,15	0,2
	ap - mm	0,5	0,5	0,5	0,6	0,6	0,6	0,6	0,6	0,6
Height Parameters	Sq - µm	2.04	2.89	4.14	1.97	2.15	3.48	2.00	2.40	2.46
	Ssk	-0.253	0.142	-0.0375	-0.147	-0.326	-0.0107	0.374	0.395	0.151
	Sku	2.50	2.61	2.19	3.53	4.15	2.61	3.34	2.49	2.34
	Sp - µm	6.50	9.50	11.5	16.3	21.1	17.8	27.0	9.80	13.6
	Sv - µm	11.8	8.20	10.8	21.9	16.1	10.8	8.80	10.3	12.8
	Sz - µm	18.3	17.7	22.3	38.2	37.2	28.6	35.8	20.1	26.4
	Sa - µm	1.71	2.32	3.47	1.57	1.65	2.78	1.68	1.99	2.10
Amplitude parameters - Roughness profile	Ra - µm	1.66	2.02	2.39	1.53	1.43	1.99	1.52	1.63	1.54
	Rz - µm	6.76	11.0	10.9	7.30	8.61	10.4	6.91	7.03	7.90

5 Conclusions

The development of additive manufacturing methods in relation to metal materials is an impulse to identifying the surface topography. The parameters of the surface topography of the hot working tool steel can differ depending on the distance from the base plate. The differences of surface roughness values for samples after printing can amount from 32% to 85% for *Ra* and from 59% to 85% for *Rz* in comparison of the sample bottom to its top. One can note also the differences in areas A, B, C what about the values of surface topography parameters in the case of turning.

References

1. S. Hong, C. Sanchez, H. Du, Journal of Electronic Materials, **44**, 3 (2015)
2. Laser CUSING® macht Rowenta-Bügeleisen ordentlich Dampf, Betrieb&Meister, **5**, 4-5 (2004).
3. K.M. Au, K.M. Yu, W.K. Chiu, Computer-Aided Design, **43**(4) 356 (2011)
4. E. Martinez, L.E. Murr, K.N. Amato, J. Hernandez, P.W. Shindo, S.M. Gaytan, D.A. Ramirez, F. Medina, R.B. Wicker, Proceedings of the 1st Int Conference on 3D Mat Sci, **73** (2012)
5. M.C. Sinirlioglu, US – Turkey Workshop On Rapid Technologies, **24** (2009)
6. I. Hatos, H. Hargitai, L. Solecki, Analysis of Tool Materials, **8**(2) 165 (2015)
7. F. Cajner, D. Landek, V. Leskovek, UDK 69.14.018.298:539.4, ISSN 1580-2949, MTAEC9, **44** (2), 85 (2010)
8. S. Wojciechowski, P. Twardowski, M. Pelic, Procedia CIRP **14,** 113 (2014)
9. S. Wojciechowski, P. Twardowski, Procedia CIRP **1**, 289 (2012)
10. S. Wojciechowski, R.W. Maruda, et al., Int J of Mech Sci, **119**, 360 (2016)
11. S. Kumar, Elsevier, Oxford, 93, DOI: 10.1016/B978-0-08-096532-1.01003-7 (2014)
12. G.M. Krolczyk, J.B. Krolczyk, R.W. Maruda, et al., Measurement, **88** 176 (2016)
13. A. Pereira, P. Hernández, J. Martinez, J.A. Pérez, T.G. Mathia, Scanning, **36**, 39 (2014)